

Why Many Undergraduate Physics Programs Are Good but Few Are Great

No single action, activity, or curricular reform will rescue a struggling physics department. Rather, it takes many elements, interacting over time, to make a department thrive.

Robert C. Hilborn and Ruth H. Howes

Scientists love to tackle mysteries; so here is one that lies at the heart of the enterprise of physics. During the 1990s, the number of physics bachelor's degrees awarded in the US dropped by nearly 25%, from about 5000 in 1990 to fewer than 4000 in 2000 (see figure 1). We won't speculate about why that decline occurred. Instead, we note that amidst the general decline, some physics departments continued to produce a large number of undergraduate majors in comparison to the typical values (see the table on page 40) for departments in institutions similar in size and degrees granted. Other departments dramatically increased the number of undergraduate majors, in some cases by factors of two or three. The puzzle: What were these thriving departments doing that led to their strong production of undergraduate physics majors in the face of a general decline—a decline shared, by the way, with engineering and mathematics?

Many possible explanations come to mind. The thriving departments may teach introductory physics in a uniquely attractive way that leads more students to major in physics. They may have new buildings lavishly equipped with fascinating research equipment. Perhaps they offer special scholarships that convince students to major in physics or attract those who would have majored in physics at other institutions. They may have watered down their curricula to make things easier for physics majors. The institutions that host thriving departments may be trying especially hard to attract more science students.

All those explanations are plausible. None, however, are true.

Undergraduate physics in the US

To find out what thriving departments do that distinguishes them from other physics departments, the National Task Force on Undergraduate Physics developed the SPIN-UP (Strategic Programs for Innovations in Undergraduate Physics) project. Operating under the auspices of the American Institute of Physics (AIP), the American Physical Society (APS), and the American Association of Physics Teachers (AAPT), the task force visited 21 thriving undergraduate physics programs, mostly during the 2001–02 academic

year. Those programs are listed in box 1; task force members are named in box 2. The SPIN-UP report describing the analysis of the site visits is available free of charge from the publications office of AAPT, One Physics Ellipse, College Park, Maryland, 20740-3842, and also through their Web site at <http://www.aapt.org/projects/ntfup.cfm>. (We note with sorrow the death, in September 2002, of task force member David Wilkinson of Princeton University. See his obituary in *PHYSICS TODAY*, May 2003, page 76.)

Some general background on undergraduate physics should help put the site visit results in context. The landscape of undergraduate physics in the US is in some ways highly heterogeneous and in other ways relatively homogeneous. Certainly the sizes and shapes of physics departments show a broad distribution. Of the roughly 1400 four-year colleges and universities in the US, about 760 offer bachelor's degrees in physics and about 170 offer PhDs. Some departments have a single member while others have 75 or more faculty members. In some cases, physics is taught in departments that include astronomy or other disciplines. Up-to-date statistics on physics departments are available through the AIP's statistical research center (<http://www.aip.org/statistics>).

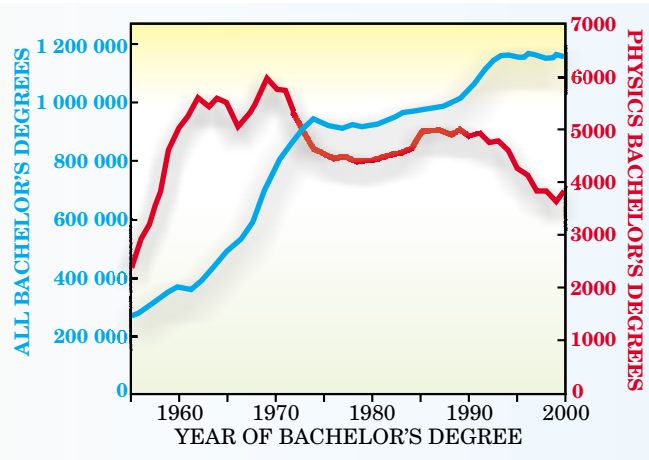
The commonality among physics departments lies in the physics curriculum. Usually in one year, most college-level introductory physics courses across the country cover a common set of standard topics that include classical mechanics and electricity and magnetism. The introductory courses are generally taught in the traditional format: lectures, laboratory exercises, and recitation sessions. Often, departments offer a mix of modern physics topics, including special relativity and quantum physics, in an additional semester or quarter. Core upper-level courses are even more homogeneous; they use a relatively small number of standard textbooks nationwide. The curricular homogeneity is somewhat surprising because, unlike chemistry and engineering, the physics community has no formal certification or accrediting process for undergraduate programs. Over the years, the physics community has reached an informal consensus about what constitutes the essential content of an undergraduate program.

About 55% of undergraduate physics majors go on to graduate school: 35% in physics and 20% in other fields. Each year, some 350 000 students take introductory physics. About half of those students take the calculus-based physics courses from which most physics majors are recruited. Among those taking calculus-based physics, only 3% take another physics course. So, by and large, introductory physics is a service course.

About 20–30% of the students who take college-level introductory physics in the US do so in roughly 1600 two-year colleges. The two-year college (TYC) system provides

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Figure 1. Physics bachelor's degrees awarded by US institutions (red) declined significantly during the 1990s even as the total number of bachelor's degrees awarded (blue) increased. Despite the general decline, though, some departments continued to thrive. The SPIN-UP project was created to find out what distinguishes those thriving departments from other physics departments. The data for the physics bachelor's degrees come from the American Institute of Physics *Enrollments and Degrees Report* (AIP, July 2002) and the data for all bachelor's degrees come from the National Center for Education Statistics *Digest of Education Statistics, 2002* (US Department of Education, 2003).



the science education for many aspiring teachers and many minority and women students. Since June 2002, project SPIN-UP/TYC, funded by NSF, has been studying physics in two-year colleges.

Several reasons motivated the establishment of a task force focusing on undergraduate physics. First, undergraduate physics plays a crucial role in the education of future physicists, engineers, medical students, and K–12

teachers. It therefore provides many students an important bridge between high school and career.

Second, undergraduate physics sets the tone for pre-college physics. For example, high-school classes are often construed as more general and somewhat less sophisticated versions of those at the college level. (If we in the colleges and universities want to complain about the poor showing of US K–12 students on international science examinations, we ought

to remember that their teachers learned both their science and how to teach it from us.)

Third, undergraduate physics is more easily “reformed” than science in the K–12 system. The tradition of departmental autonomy in most colleges and universities means that physicists themselves essentially determine the shape and form of undergraduate physics programs. Thus, the chances of implementing significant improvements in a relatively short time are much greater in undergraduate departments than they are in the K–12 system.

The site visits

To identify thriving physics departments, the task force first studied the AIP statistics on bachelor's de-

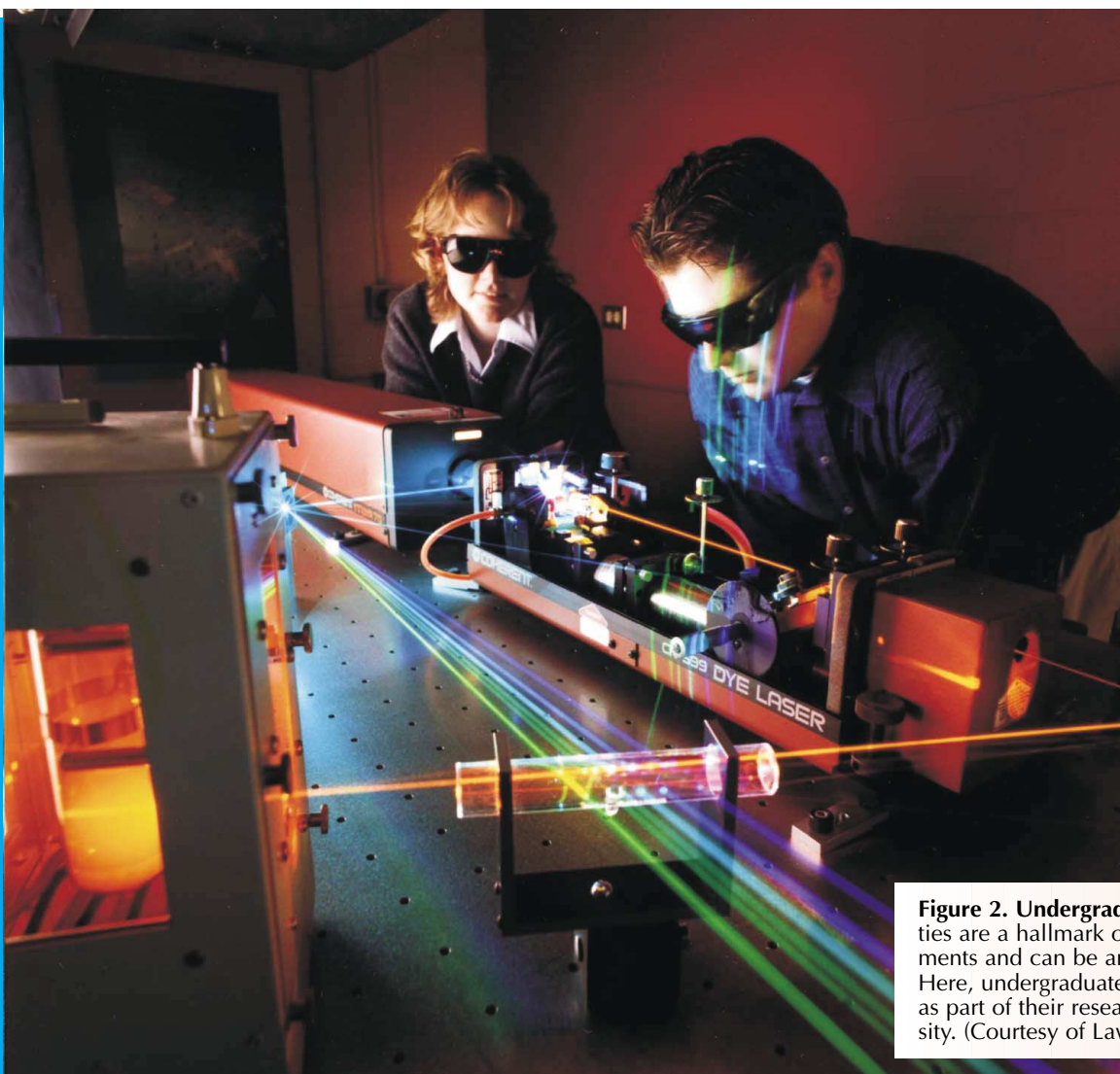


Figure 2. Undergraduate research opportunities are a hallmark of thriving physics departments and can be an effective recruiting tool. Here, undergraduate students are tuning a laser as part of their research at Lawrence University. (Courtesy of Lawrence University.)

degrees awarded over the past several years, looking either for large numbers that had been sustained for many years or for numbers that increased dramatically in the late 1990s. The identified departments produced at least twice (and in some cases five times) the average number of undergraduate majors for comparable institutions. Task force members then looked for other evidence of lively programs, such as undergraduate research participation or Society of Physics Students (SPS) chapters. Seeking to visit a diverse group of institutions, the task force chose departments from 21 institutions, some public and some private, with a mix of locations and department sizes.

Site visits typically lasted 1½ days. Each site visit team met with physics faculty members; with physics students, both majors and nonmajors; and in most cases, with faculty members in other science departments and with university administrators. After the site visit, the team composed a written report that was checked for accuracy by the department chair. Each report was distilled down to a three-page case study, available online at the SPIN-UP report site.

The task force analyzed the site visit reports and extracted a relatively small number of features that characterize successful undergraduate physics programs. They backed up each of their conclusions with evidence from the site visits and chose exemplars of the various features so as to give some sense of the breadth of activity in the departments visited. Those examples, some of which are presented below, are not intended to endorse a particular activity as the best practice for a particular feature: Almost all of the departments visited shone in nearly all of the features we describe. However, it is difficult to establish a precise cause-and-effect relationship for any of the features taken individually. The collective effect, on the other hand, is striking.

Common elements and emerging themes

When the features that characterize thriving departments are looked at as a whole, three major themes emerge:

► Building a thriving undergraduate program involves more than curricular reform. A flourishing program is challenging, but supportive and encouraging. It includes a well-developed curriculum, advising and mentoring, an undergraduate research program, many opportunities for informal student–faculty interactions, and a strong sense of community that enhances those interactions. In addition, the department emphasizes interactions with students as team members in departmental efforts such as outreach to the public and to K–12 schools.

► The department is the critical unit for change in undergraduate education. Individual faculty members, of course, develop the ideas and carry out the activities, but the support of a large fraction of the department is crucial if the changes are to have lasting impact. Widespread among faculty at a thriving department is the attitude that the department has the primary responsibility for maintaining or improving the undergraduate program. Moreover, a thriving department generally has a strong disposition toward continuous evaluation of and experimentation with the undergraduate program. Rather than complain about the lack of students, money, space, and administrative support, such a department initiates reform efforts in

areas that it identifies as most in need of change. Institutional support is important, but the action takes place at the departmental level.

► All reform is ultimately local. One size does not fit all for serious educational innovation. A successful department enjoys strong and sustained leadership. It has a clear and realistic sense of the mission of its undergraduate program and is able to identify the resources needed to carry out that mission.

More than a strong curriculum

Thriving physics departments do much more than teach courses. Many features combine to create a successful program. One integral element is an advising program that actively reaches out to students and supports all physics majors no matter what their career plans. Some departments use a centralized advising system; others disperse the advisees among the department's faculty members.

For example, the undergraduate program director in the department of physics and astronomy at Rutgers University handles all of the advising for undergraduate majors. The faculty and the departmental leaders believe centralizing the undergraduate advising is the most important factor that has led to the growth in the number of physics graduates, which doubled from about 20 in 1980 to 40 in 2000. The students support that conclusion and express strong appreciation for the director's concern for them as individuals and for the consistency of the advice they receive.

At Carleton College, the advising system is different. There, students don't declare their majors until the spring of the sophomore year. Faculty members make use of the introductory physics courses to develop a personal connection with each of their students, and that connection provides a springboard for faculty advising that continues throughout the student's undergraduate career.

Advice need not be limited to physics or academics. Most of the departments that were visited make a serious effort to provide students with information about careers. The programs take many forms, but most include an active effort to make students—particularly beginning students—aware of the wide range of careers possible with a physics degree. For upper-level students, the mentoring includes advice on how to apply for jobs and graduate schools and how to prepare for interviews.

Bethel College in Minnesota maintains close ties with high-tech industries in the Minneapolis–St. Paul area and places many students in internships with those industries. The entire physics faculty at Bethel meets to match students with available internships. As an added bonus, the connection between college and industry often leads to equipment donations and funded research contracts.

Most physics students benefit from an undergraduate research experience (figure 2), no matter what their career plans. As with most physics departments these days, the departments visited provide many opportunities for undergraduate research, either during the summer or during the academic year. The departments encourage students, sometimes as early as the sophomore year, to participate in research.

Reed College emphasizes undergraduate research and independent work that supports Reed's overall focus on

Size of Physics Bachelor's Class by Type of Department, Class of 2000.

Department type	Degrees per department	
	Average	Median
Bachelor's granting	3.2	2
Master's granting	4.7	4
PhD granting	10.7	8

*Source: AIP Statistical Research Center, *Enrollments and Degrees Report*, July 2002.*

Figure 3. Students present research posters at North Carolina State University's annual physics department undergraduate research symposium. (Courtesy of North Carolina State University.)

close student–faculty research collaborations. Four of Reed's physics majors have been recognized for their research work by the APS LeRoy Apker Award (one winner, three finalists). All Reed students do a senior thesis project. External research funding in the department has exceeded \$2 million over the past decade.

At Bryn Mawr College, students taking the introductory physics courses are given tours of the research laboratories. Upper-level students involved in those laboratories give presentations to beginning students at a mini-symposium. Many students cite the research opportunities as playing an important role in their decisions to become physics majors.

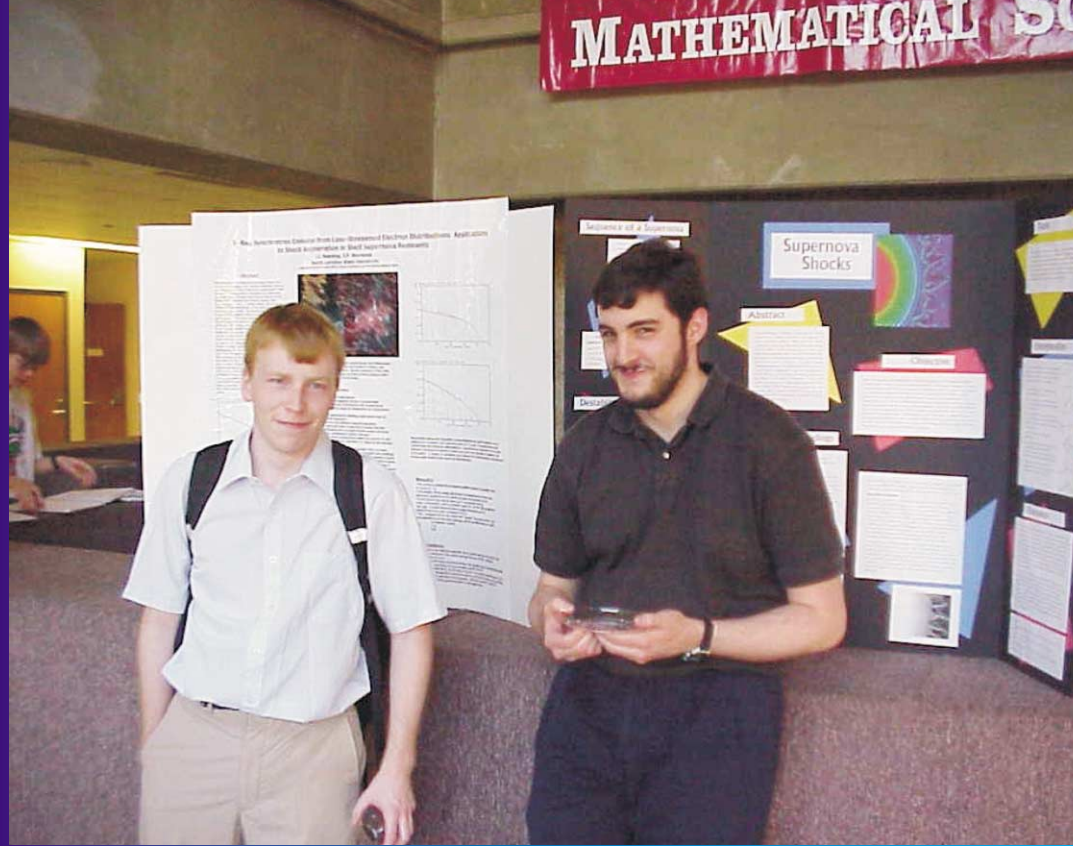
Bryn Mawr's approach illustrates that most departments that were visited have some sort of recruitment program involving high-school or first-year students. On the other hand, the type of recruitment varies widely from institution to institution.

The Bryn Mawr example also shows that the mentoring relationship need not be between faculty and students. There, upper-level students offer laboratory presentations. Figure 3 illustrates another way in which students can serve as role models: At North Carolina State University, poster sessions at a local symposium allow advanced students to present their research results to their peers.

Alumni can provide valuable help and advice to the students at their alma maters. Most thriving departments keep in contact with alumni. Many maintain data on the careers of alumni and often invite them back to talk to current students and faculty or to assist in arranging internships and research experiences for current students.

Successful departments encourage informal student–faculty and student–student interactions. They use picnics, softball games, invited speaker talks, bridge-building contests, and so on. All of the departments that were visited have an active physics club or SPS chapter (see figure 4). The departments often provide a student common room or lounge.

At California Polytechnic State University, the active SPS chapter helped set up a centrally located physics majors' lounge called h-bar. That space provides an area for informal student–faculty and student–student interactions. Students tutoring other students also use the lounge. It has ample whiteboard space and is adjacent to the project rooms, where seniors have workspace for research activities. Students—from first-year to senior—at test to how they make use of the lounge for study groups, how the more senior students help the less experienced



ones, and how h-bar leads to remarkably high community spirit.

A departmental team effort

In all the visited programs, a large fraction of the department is actively engaged in the undergraduate program. That engagement includes some means of mentoring new faculty, particularly for teaching. Thriving programs don't leave the responsibility for the undergraduate program to just senior members who are no longer active in research, to junior faculty, to adjuncts, or to a few heroic faculty members. Undergraduate education is a team effort.

For example, seven years ago, the department of physics at the University of Illinois at Urbana-Champaign began a major revision of the calculus-based introductory physics sequence designed for physics majors and engineers. A team of eight faculty members, aided by a reduced teaching load, worked on the revision over several years. They built a solid infrastructure based on faculty teams teaching a series of courses. At present, nearly 75% of the department's faculty members have taught in the revised course sequence and have enjoyed the experience.

The Colorado School of Mines has a noteworthy mentoring program. The head of the physics department regularly has lunch with junior faculty and sends all new faculty to the new physics and astronomy faculty workshops run by AAPT and APS. When new faculty members are assigned to teach the introductory courses, they first serve as apprentices with more senior faculty. New teachers trade classroom visits with experienced colleagues as part of the university's peer enhancement of teaching program.

A successful program is recognized and supported by its institution's administration. Many of the departments that received site visits are viewed as campus leaders in educational innovation, including undergraduate research participation. The administration rewards the department's efforts because they support the goals of the institution.

At Grove City College, the dean of science and engineering and the provost report that the physics depart-

Box 1. Departments Visited

Angelo State University, San Angelo, Texas
Bethel College, St. Paul, Minnesota
Brigham Young University, Provo, Utah
Bryn Mawr College, Bryn Mawr, Pennsylvania
California Polytechnic State University, San Luis Obispo
Carleton College, Northfield, Minnesota
Colorado School of Mines, Golden
Grove City College, Grove City, Pennsylvania
Harvard University, Cambridge, Massachusetts
Lawrence University, Appleton, Wisconsin
North Carolina State University, Raleigh
North Park University, Chicago, Illinois
Oregon State University, Corvallis
Reed College, Portland, Oregon
Rutgers University, New Brunswick, New Jersey
State University of New York Geneseo
University of Arizona, Tucson
University of Illinois at Urbana-Champaign
University of Virginia, Charlottesville
University of Wisconsin-La Crosse
Whitman College, Walla Walla, Washington

ment's dedication to good teaching in its service courses has been a major contributor to the "rise of physics" on the Grove City campus. Over the past nine years, the number of faculty has increased from three to five to support the increasing number of physics majors and the expanding role of the physics department in teaching service courses to nonmajors.

Departments at large institutions can also play an important role in offering service courses. About half of all the undergraduate students at the University of Virginia have taken at least one course in the physics department. Many nonscience majors take one or two semesters of "How Things Work" or "Galileo and Einstein," or a conceptual physics survey course. The physics department has an excellent reputation among nonscience students at Virginia.

Thriving departments all pay special attention to the introductory physics courses, and many assign their most skilled teachers to those courses. They are also aware of the findings and pedagogical innovations from physics education research. (See the article by Edward Redish and Richard Steinberg in *PHYSICS TODAY*, January 1999, page 24.) Some departments have one or two faculty members actively engaged in physics education research. Several faculty members have received external funding for education projects.

North Carolina State University has long been active in physics education research and, within the past two years, has hired two additional faculty members in that field. At present, three sections of the calculus-based introductory physics course use the methods of Project Scale-Up, an NSF-funded effort that has been developing means for using interactive-engagement techniques in large introductory courses.

Local reform

A successful department typically has a clearly articulated undergraduate mission and an understanding of how that vision supports the mission of the institution. The vision is shared among the faculty and communicated to the students. At the same time, thriving departments are realistic about the kinds of students they are likely to recruit.

Brigham Young University maintains a modest graduate program in physics with about 25 graduate students.

The department, however, has made a strong commitment to undergraduate physics with an emphasis on undergraduate research; 30 000 of BYU's 32 000 students are undergraduates.

Potential physics majors come to their institutions with a wide range of abilities and interests: A successful program can adapt to that diversity. Most of the departments that received site visits have flexible majors' programs in which several options or tracks lead to the bachelor's degree.

Harvard University graduates 50–60 physics majors each year and its physics department supports two levels of majors. The basic program requires a total of 12 courses in physics and mathematics. The honors program requires an additional two advanced mathematics courses, an extra advanced lab course, and three additional physics courses. Harvard also offers several joint-major programs: physics and chemistry, physics and mathematics, physics and astronomy, physics and history of science, as well as a biophysics option and a program for those intending to teach physics at the secondary-school level.

Dual-degree engineering programs, which offer physics and engineering degrees after an extended period of study, are useful recruiting tools for many physics departments, particularly those at four-year colleges that don't have engineering departments. For example, SUNY Geneseo admits about 40 students each year who are interested in spending three years at Geneseo as part of its 3–2 dual-degree engineering program. Many of those students are subsequently recruited to be physics majors, finish a physics major program at Geneseo in four years, and then pursue graduate studies in engineering.

Successful departments enjoy sustained leadership with a focus on undergraduate physics within the department. The leaders work hard to see that most department faculty members place a high value on undergraduate education.

In some cases, strong leadership has revived a dying department. The physics department at the University of Wisconsin-La Crosse faced almost certain extinction in the late 1980s. The dean of faculty recommended and supported the hiring of a new chair from outside the university. The new chair took the lead in convincing others in the department that they could have a thriving physics program. He and his successor, with support from the administration, increased and improved staffing and faculty research and restructured the curriculum. After two years of negotiations within the department and with the administration, the department put in place recruitment efforts, opportunities for undergraduate research, and a 3–2 dual-degree engineering program. Subsequently, the number of physics majors increased dramatically, from 1 per year to nearly 20 per year. The cover of this issue of *PHYSICS TODAY* shows a physics faculty member and students in the University of Wisconsin-La Crosse planetarium.

A question of diversity

Women and minorities are distinguished by their lack of presence in the science, technology, engineering, and mathematics (STEM) disciplines. Their absence is particularly striking in the physical sciences, mathematics, and engineering. (NSF's *Science and Engineering Indicators 2002*, available online at <http://www.nsf.gov/sbe/srs/seind02>, gives the detailed statistics.) Participation is increasing, but it is still far below the overall participation of women and minorities in undergraduate education. There is much speculation about that lack of representation, and we need not rehearse those speculations here.

The SPIN-UP site visits, though, did uncover one sur-



Figure 4. Society of Physics
Students events, such as this 1999 gathering at Angelo State University, allow students and faculty members to interact informally. Consistent with the theme of “yesterday, today, and tomorrow,” note the appearance of Isaac Newton, an aluminum mushroom cloud, and the Y2K bug. (Courtesy of Andrew Wallace, ASU.)

Comments and cautions

There is no single action or activity or curricular change that will make an undergraduate physics program thrive. Indeed, it is the interaction of many elements that seems to be key. Most struggling departments have some of the features identified in the successful departments, but the

prise: The task force had anticipated that thriving departments would have substantial success in bringing women and minority students into physics. Most of the departments did, in fact, do a bit better than the national average in graduating underrepresented students. But they didn’t do a lot better. That finding surprised all of the site visit teams, because of the folklore among those who are actively working to increase the participation of underrepresented groups in STEM disciplines. According to popular belief, active, supportive programs will be highly successful in graduating women and minority students. Our conclusion is that those programs have the conditions necessary for success, but those conditions are not sufficient. The article by Barbara Whitten and colleagues on page 46 describes several physics departments that have been successful in graduating women from undergraduate physics programs. The task force is working with Whitten and colleagues to understand the difference between the departments she and her team visited and those visited by the SPIN-UP teams.

interactions and the focus on undergraduate physics are lacking. There are many good undergraduate physics programs; there are few great ones.

That’s not to say that the 21 departments visited by task-force members are the only terrific departments, or that they are perfect. The task force turned up at least two dozen additional departments it would have been delighted to visit if time and resources had been available. The departments they did visit all recognize that room for improvement remains even in the most successful programs. In fact, thriving departments are characterized by their ongoing efforts to improve.

Most of the crucial features of a successful department do not require major external funding. The critical resource is personnel—dedicated and energetic and perseverant—with a vision for a thriving undergraduate physics program. That vision is understood and clearly articulated, not only within the department, but also in the institution’s administration. Nevertheless, we don’t wish to downplay the importance of resources: The department

must have at least modest resources, both financial and human, that will allow experimentation with the curriculum and support for student research, a physics club, and so on.

But even a department with committed personnel and adequate resources shouldn’t expect improvement to be immediate. It took departments several years to initiate changes and to build a thriving program. Changes take time to settle in and to make an impact. Moreover, what works for one institution may need to be adapted and modified for use at another.

Box 2. National Task Force on Undergraduate Physics

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We emphasize that none of the thriving departments have watered down their undergraduate programs to attract and retain majors. Although the site-visit teams made no attempt to measure student learning directly, they did look at indirect evidence of what students have learned—the quality and sophistication of research projects, employment of graduates, and admission to graduate programs in physics or closely related fields. By those indirect measures, the departments that were visited have rigorous curricula that prepare their students well for a variety of careers. Some of the thriving departments seem to recruit many majors from would-be engineers, mathematicians, or computer scientists just because the physics program is viewed as intellectually challenging. The key element is the sense of community that the students and faculty have established.

The National Task Force on Undergraduate Physics is committed to the improvement of undergraduate physics, which plays a crucial role in educating the next generation of scientists and engineers, the next generation of K–12 teachers, and the future leaders of our society. The conclusions drawn from its SPIN-UP project, although focused on physics departments, agree with the results of an analysis of several undergraduate science disciplines and a series of visits to thriving undergraduate mathematics programs. (See the first two of the further readings at the end of this article.) Those conclusions provide a blueprint for what is needed to build a thriving undergraduate physics program. That blueprint, however, must be adapted to fit local conditions—the students each department serves, the faculty and physical resources available, and the mission of the home institution.

The task force is currently seeking funding for consulting visits to physics departments that want to revitalize their undergraduate physics programs and for a series of regional workshops for physics departments that want to develop strategic plans for their undergraduate programs. It is also developing several means to analyze diversity issues in undergraduate physics.

Although the amount of work to revitalize an undergraduate physics program may seem daunting, we trust that the examples set by the 21 SPIN-UP departments that were visited provide an existence proof of the practicality of such efforts. We are convinced that, with sustained efforts, every physics department can have a thriving program that challenges and supports students and in which faculty approach undergraduate physics as a scholarly enterprise worthy of the problem-solving and critical-thinking skills that sustain them as researchers.

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Further reading

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